SPECIAL REPORT 96-7

CRREL

Dusting River Ice with Leaf Mulch to Aid in Ice Deterioration

Robert B. Haehnel, Charles H. Clark and Susan Taylor

April 1996

Abstract

In an effort to find a low cost means of reducing ice jams on small rivers in New England, dusting with organic matter was field tested during the spring of 1993 and 1994. Test squares on a pond located at CRREL in Hanover, New Hampshire, were dusted with several materials to evaluate their effectiveness in accelerating snow melting and ice deterioration. Leaf mulch was included in the materials tested because, unlike other materials used in the past to weaken ice (e.g., fly ash or coal slag), leaves are naturally found in rivers and should not adversely affect aquatic organisms when applied in small quantities. It was found from these tests that the leaves perform about the same as the traditionally used dusting materials. To transfer what was learned at the pond tests to a field application, two rivers in Vermont, with a known history of ice jams, were dusted using leaf mulch during the spring of 1994. Since these sites were located on narrow rivers that wind through highly populated areas, aerial dusting was not possible. For these sites we used a hydroseeder to spread the leaves on the ice. Application of leaf mulch with a hydroseeder was found to be an efficient method of putting the leaves on the ice. After the rivers were dusted we had a heavy snowfall, and were not able to determine the effectiveness of the leaf mulch in melting the ice. Observations suggest, however, that the leaf mulch helped melt the overlying snow. More work is needed to determine the effectiveness of leaf mulch to weaken ice and how much ice weakening is necessary to reduce the severity of ice jams.

For conversion of SI units to non-SI units of measurement consult ASTM Standard E380-93a, *Standard Practice for Use of the International System of Units,* published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.

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U.S. Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

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Prepared for
OFFICE OF THE CHIEF OF ENGINEERS

PREFACE

This report was prepared by Robert B. Haehnel, Research Mechanical Engineer, and Charles H. Clark, Electronics Technician, Ice Engineering Research Division, and Susan Taylor, Research Physical Scientist, Geological Sciences Division, Research and Engineering Directorate, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire. Funding for this research was provided through the U.S. Army River Confluence Ice Program, Work Unit 32972.

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ROBERT B. HAEHNEL, CHARLES H. CLARK AND SUSAN TAYLOR

INTRODUCTION

The decay of river ice depends not only on the ambient air and water temperature, but also the absorption of solar radiation into the ice. Ashton (1985, 1986) shows that once the ambient air temperature reaches freezing, the rate of deterioration of the ice cover (i.e., structural weakening of the cover) depends greatly on the absorption of the solar radiation by the ice cover. Thus reduction of the albedo (reflected solar radiation/solar radiation incident to the surface) of the ice surface can contribute to accelerated decay of an ice cover. This, in turn, can reduce the potential for ice jam formation on a given river reach during ice breakup.

Dusting (application of a dark material to a snow/ice surface) can be used to hasten ice cover deterioration by reducing the albedo of the snow/ice surface (for a review of dusting applications, see Slaughter 1969). Typical albedo values for "black" or clear ice are about 20% (Perovich 1992), while "white" ice—which contains air bubbles, snow ice or frazil—can have albedo values as high as 60 to 80% (Prowse and Demuth 1992). Albedo values for fresh snow can be as high as 90%. However, as snow ages the albedo decreases. A typical value for this old snow is around 50% (Colbeck 1988). Depending on the type of "dust" used and the amount applied, dusting can reduce the albedo of a snow or ice surface to 15 to 20% (Williams 1967). Thus, dusting can be used to increase absorption of solar radiation in all but black ice. However, if snow is on top of this black ice, dusting can be used to accelerate the ablation of the overlying snow, allowing the sunlight to get to and melt the ice faster than would occur naturally.

The dusting material is frequently put on the ice using an aircraft. Examples of this include dusting operations on Yukon River in Galena, Alaska (U.S. Army Corps of Engineers 1968) and on the Platte River near Omaha, Nebraska (U. S. Army Corps of Engineers 1979, 1994a). During the first few years that the Yukon River was dusted, a modified B-25 aircraft was used to spread river sand on the ice. More recently crop-dusting aircraft have been used to spread the river sand on the ice. The dusting operations that have been carried out on the Platte River use crop dusting aircraft as well; however, on the Platte coal slag was used as the dusting material.

Although aircraft are well suited for dusting large rivers, such as the Platte, many rivers, such as those found in New England, cannot be dusted using aircraft because they are narrow and are lined by trees and dwellings. We found it necessary to develop a new way to apply dusting materials on these small rivers. Also, coal dust and slag are considered a threat to the riverine aquatic life due to the contaminants they contain. Furthermore, small particles such as sand, coal dust, and slag can also be a problem in many New England rivers since they tend to clog the spaces between rocks where the fish like to lay their eggs and thereby inhibit reproduction. The above environmental concerns led us to explore the use of biodegradable dusting materials that might be more environmentally friendly.

This report details the use of leaf mulch, which was spread on two rivers in Vermont using a hydroseeder. We describe the performance of the leaves as a dusting material, and the usefulness of a hydroseeder in applying the leaves.

EVALUATION OF DUSTING MATERIALS

During the winters of 1993 and 1994, several dusting tests were conducted on an ice covered pond at CRREL in Hanover, New Hampshire. Figure 1 shows a typical test plot setup on the pond. The purpose of these tests was to evaluate the effectiveness of several organic dusting materials at melting snow and ice. During these tests the snow

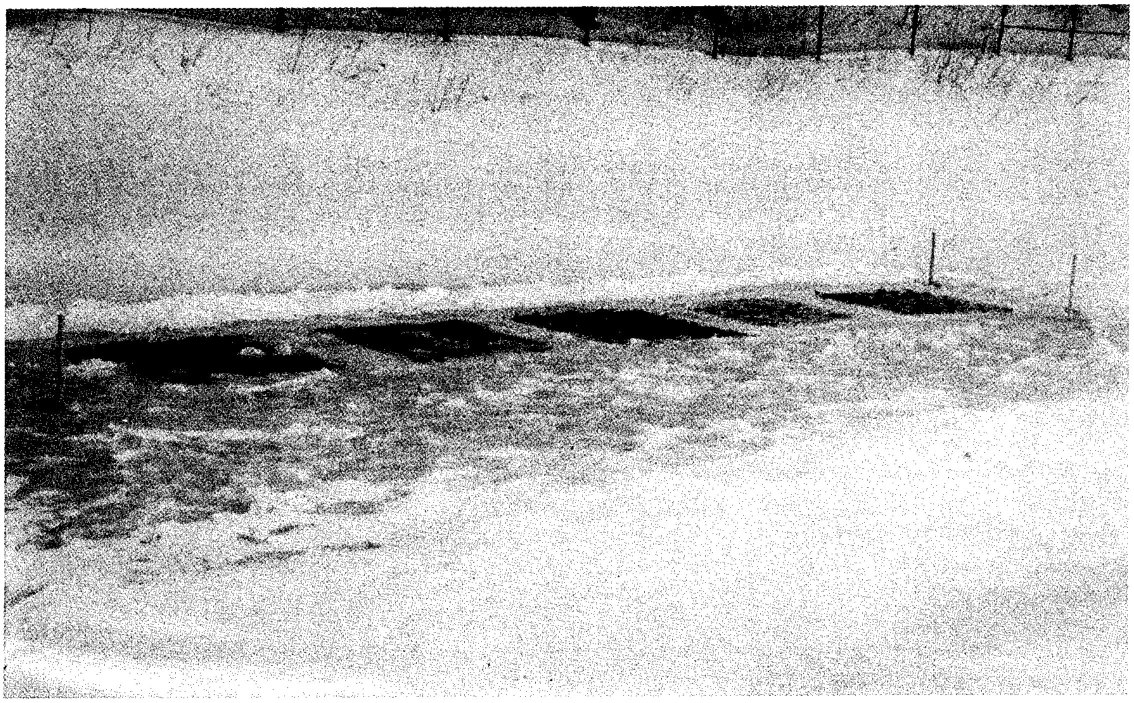


Figure 1. Test setup for evaluation of dusting materials on ice-covered pond (March 1994).

and ice thickness was measured and compared to a control area that was not dusted. We also measured the albedo of these materials and of the snow.

Dusting tests

In March of 1993 four, 65-in. (1.65-m) square test plots were marked on the pond's surface. In this test we compared the performance of bark, hay and leaves to sand. Each test square was dusted with 960 mL of material, one material on each square. The control was the ice cover adjacent to the test squares. All the test materials were immersed in water overnight and were applied wet, to prevent them from blowing away. A day after this test was started (20 March) 13 cm of snow fell. Within two days of the snowfall (22 March) the snow over the test plot with leaves on it had melted off. The other test materials also melted the overlying snow more quickly than untreated areas but they did not become uncovered until the 26th of March, four days after the leaves were exposed. Due to heavy snowfalls the remainder of the winter no further evaluations could be made.

On 18 February 1994 a test site was again set up on the pond with five test squares. There was 30 cm of ice and between 5 and 10 cm of snow on the test area. Again, hay, sand, bark and leaves were used but this time both wet and dry leaves were applied. During the first day the wet leaves melted further into the snow than did the dry leaves; wetting the leaves decreased their albedo about 5–10%. By the following day the leaves that were applied dry were wetted by their meltwater, and thereafter the two plots of leaves performed similarly. The snowfall and cold weather over the next few weeks resulted in little melting. However, by 1 April the snow over the test areas was 9 cm below the surrounding snow level, suggesting that the underlying test materials were melting the overlying snow. By 14 April the snow in the test area was gone and the entire test area was under 13 cm of water; both the hay and the bark were floating on the water. There was still, however, snow on the ice adjacent to the test areas. Since the ice had become too weak to walk on, no further measurements were taken.

Figure 2 shows the measured snow and ice thicknesses throughout the test. The ice measurements are indicated by the thick lines, while the snow depths are indicated by the thin lines. Figure 2 shows that the sand and leaves performed equally well at melting snow and ice. However, the bark was not only less effective at melting snow, but there was no noticeable melting of the ice under the bark.

We also noted that since both the hay and bark float and they were easily washed off, so that they

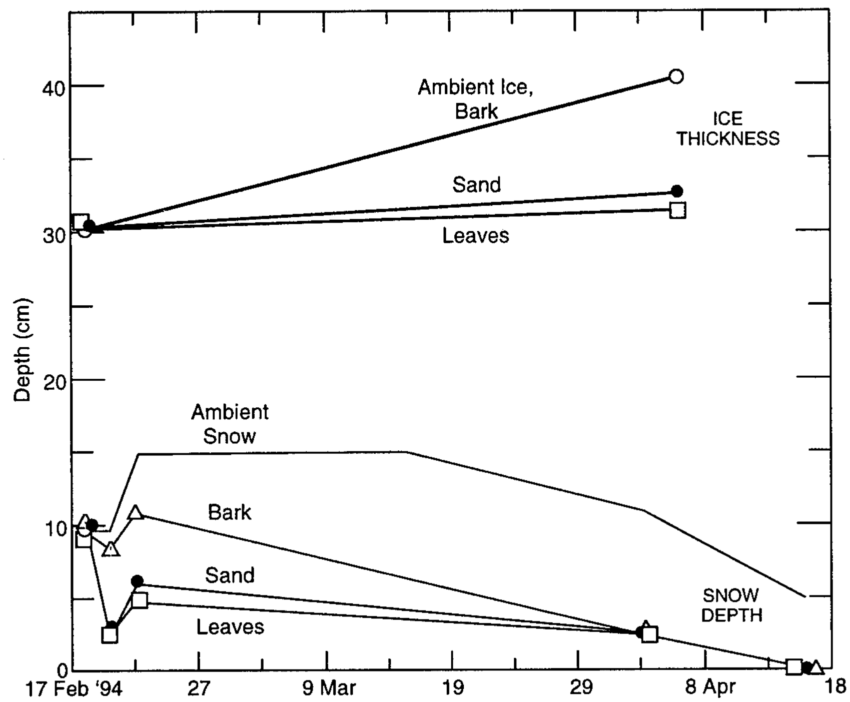


Figure 2. Snow depth and ice thickness in test plots and control on ice-covered pond.

were not effective once the surface was covered with meltwater. Leaves and gravel were heavier than water and stayed on the ice surface even when there was meltwater on the surface of the ice. We also found that wetting the organic materials had the advantage of hastening melting in the early stages of the tests, and prevented the material from being blown around by the wind during and immediately after application.

Albedo measurements

In March of 1994 we made albedo measurements of snow and dusted snow on the frozen pond. Also, spectral reflectance* measurements were made of samples of snow and of the pure dusting materials (hay, leaves, bark, sand, and coal dust). These measurements allowed us to identify what materials might be most effective for reducing the albedo of a snow or ice surface.

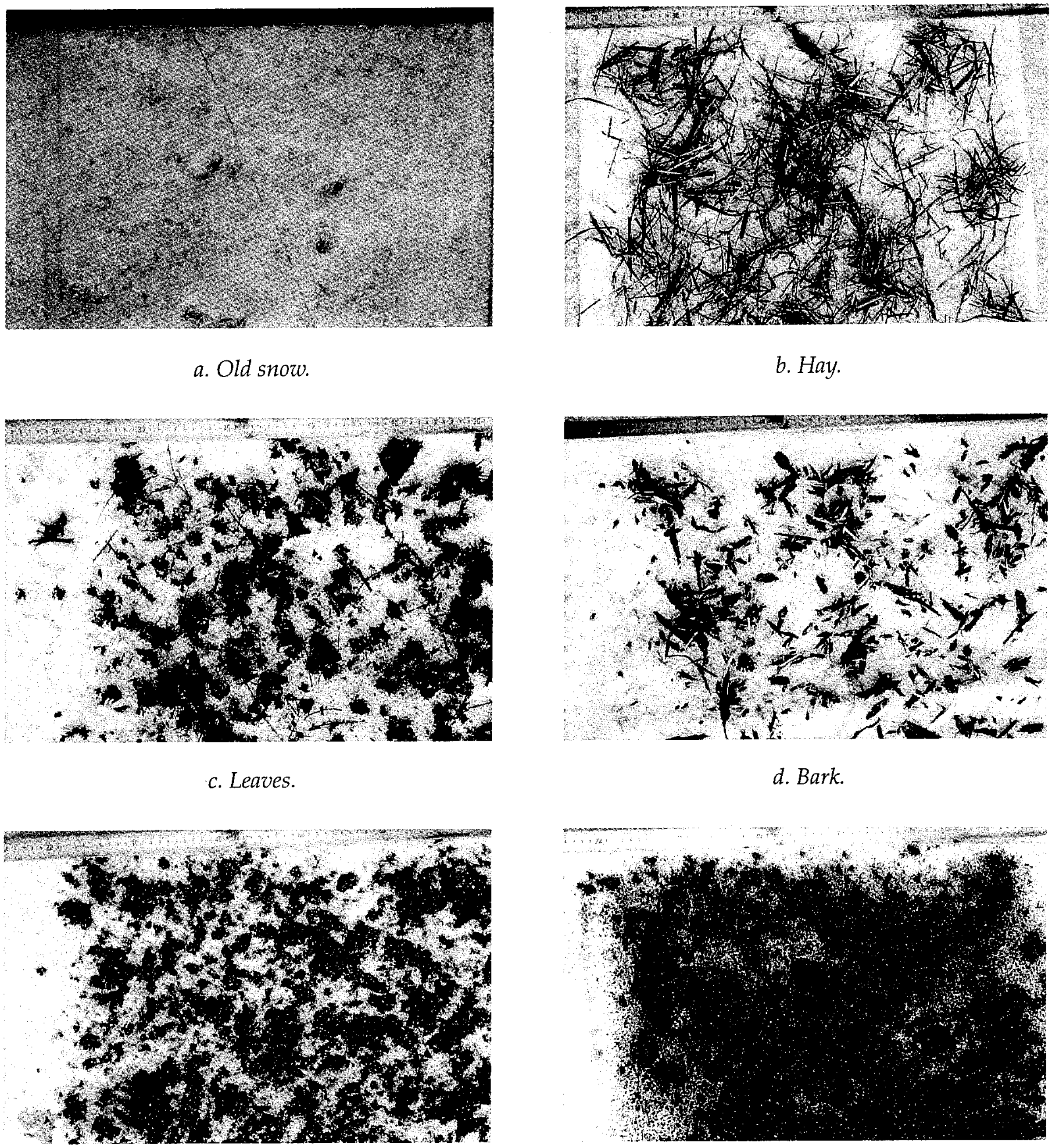
All of the measurements were made using a Analytical Spectral Devices field portable radiometer. The measurements covered the visible and near-infrared portion of the spectrum (400–1000 nm).

The albedo measurements were made on separate test plots from those described above. No special preparations were made to the snow before application of the materials. The dusted areas were 60 × 60 cm and all the measurements were made 30 cm from the ground. The test areas had 1000 cm^3 of material spread on their surfaces (except the coal dust which had only had 750 cm^3 of material). The albedo was measured with a hemispherical cosine collector. This gathered radiation from the entire 3600-cm^2 test area. Photographs of the test plots are shown in Figure 3. The albedo measurements are shown in Figure 4.

Figure 3a shows that the snow in the control area is coarse grained and dirty, an observation confirmed by a low albedo of 50%. This is a typical value for late winter "corn" snow. The dusting materials decreased the albedo of the snow by varying amounts, with hay being the least effective and coal dust being the most effective. Of the organic materials leaves were the most effective at reducing the albedo of the surface.

For measuring the reflectance of the of pure material samples, each material was placed in a separate container that was about 7.5 cm in diameter.

*Spectral reflectance is the ratio of radiation reflected by the sample to that reflected from a standard (the standard reflects greater than 99% of the solar radiation, Labsphere 1988).



a. Old snow. *b. Hay.*

c. Leaves. *d. Bark.*

e. Sand. *f. Coal dust.*

Figure 3. Surfaces on which the albedo measurements in Figure 4 were made (March 1994).

Due to the small area of these samples (about 45 cm^2) we required an instrument with a much smaller footprint than a cosine collector used for albedo measurements. Thus, for these samples we made spectral reflectance measurements using an attachment with a 1° field of view (the resulting footprint was 0.75 cm^2). These measurements were taken 30 cm from the surface of the samples. The results of these measurements are shown in Figure 5.

Figure 5 shows that all of the pure materials, except snow*, are quite dark in the visible (400–700 nm). The sand has the highest reflectance of the materials at the 400–550-nm wavelengths (blue

*The spectral reflectance measurements shown in Figure 5 for are for fresh snow; consequently the reflectance for this snow is higher than that of the old snow shown in Figure 3.

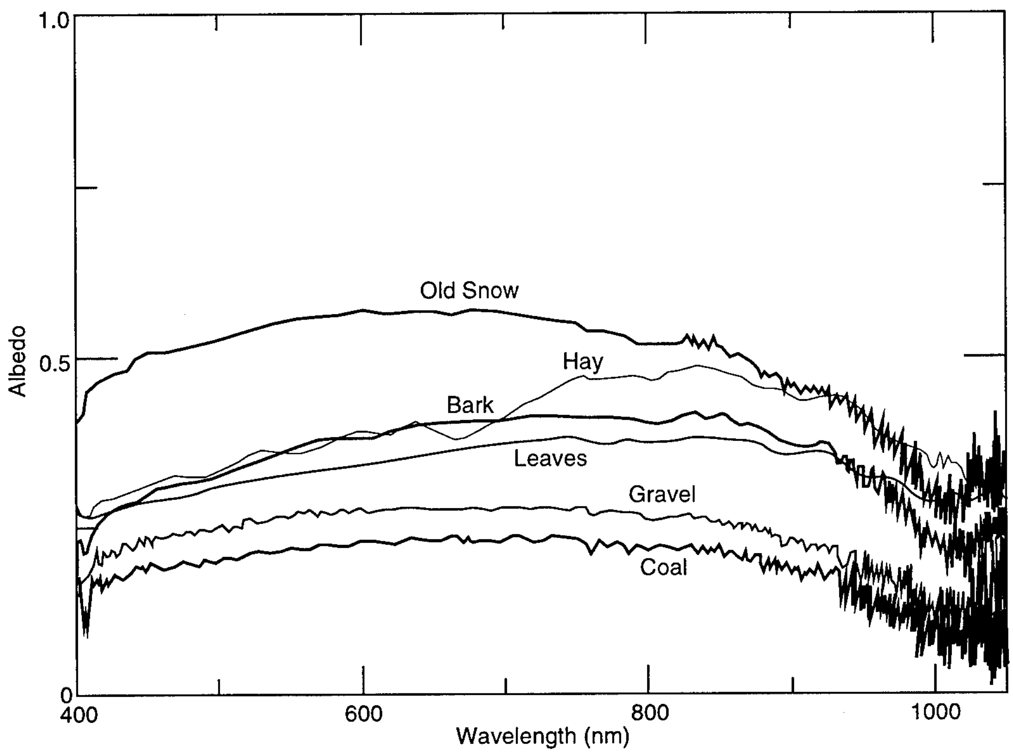


Figure 4. Albedo measurements of the dusted surfaces (March 1994).

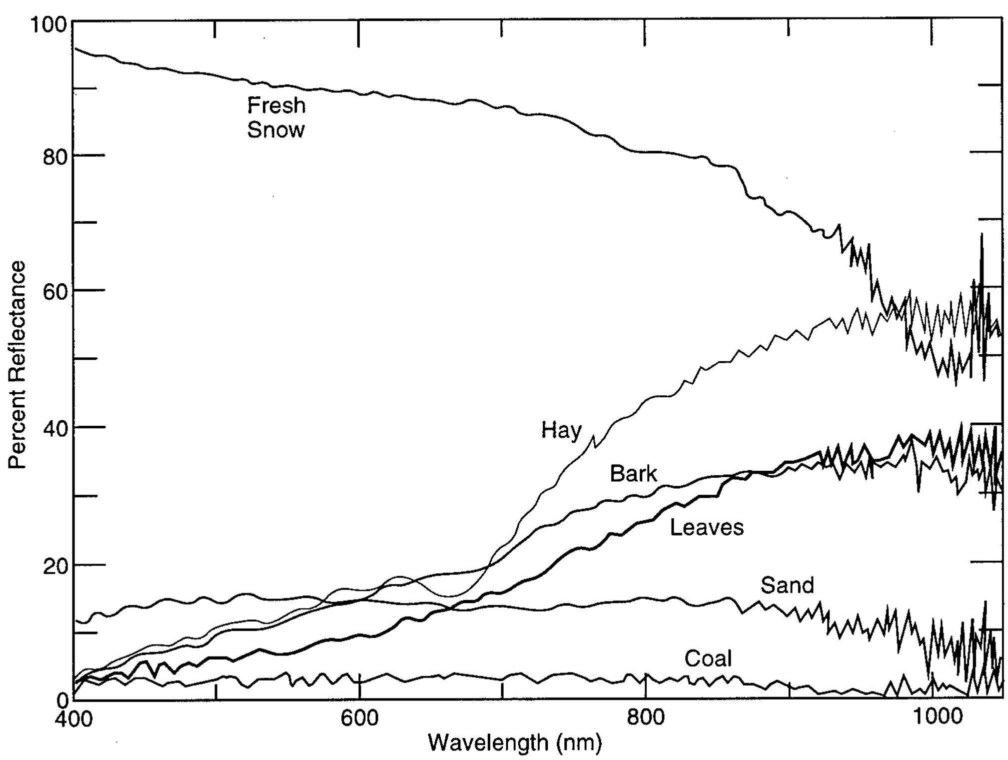


Figure 5. Spectral reflectance measurements of fresh snow and the pure materials used on the test areas shown in Figure 3 (March 1994).

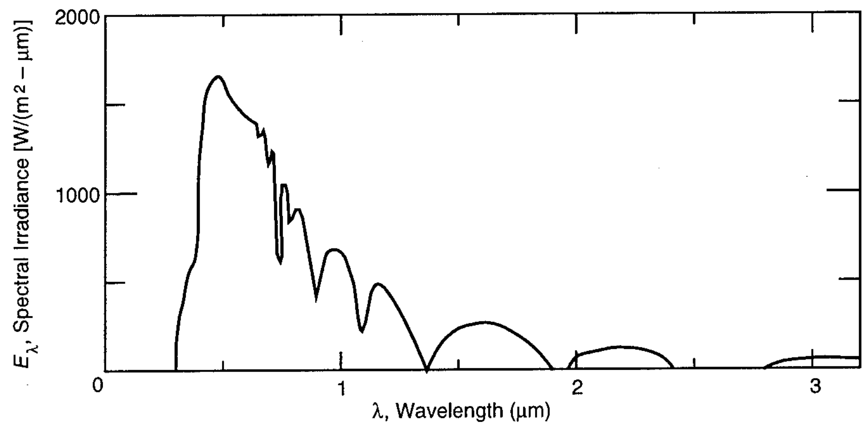


Figure 6. Solar spectral irradiance at the earth's surface (from Swain and Davis 1978).

and green) and reflects about 15% of the radiation it receives. Hay, bark and brown leaves have a low reflectance through most of the visible region but have higher reflectance in the infrared than coal or gravel. The high reflectance of the plant materials in the infrared is due to the plants' cell structure (Hoffer 1978). We note that the wavelengths at which dead leaves absorb the most radiation (400–700 nm) are those where snow is the most reflective (Fig. 5) and also those wavelengths corresponding to the sun's peak radiation (Fig. 6). Consequently, we found that leaves could be used to effectively lower the albedo of snow, and would likely be an effective dusting material.

FIELD TESTS OF LEAF MULCH

Having determined from the tests on the pond that leaves might be an effective alternative to dusting with coal dust, slag or sand, we conducted two field trials during the spring of 1994. The purpose of these trials was to test using a hydroseeder to apply biodegradable dusting materials to river ice. Additionally we measured the depth of the snow and ice in the test reaches during the test to further document the performance of the leaves as a dusting material. The field trials were conducted on the Winooski River in Montpelier, Vermont, and on the White River in Hartford, Vermont. The sites were chosen because they are locations where ice jams have frequently formed in the past, resulting in flooding and damages.

In addition to measuring ice thickness, snow depths, and air temperature during the melt period, we estimated the incident solar radiation. Estimates were obtained by decreasing the expected solar radiation (computed from the time of day, latitude, and Julian day) using hourly cloud cover data and the procedure outlined in Appendix A.

We also documented the areal coverage (fraction of the ice covered by the leaves) by photographing the dusted area and then using an image analysis program to determine the relative fractions of the snow and leaves. The process is illustrated in Figure 7. Figure 7a is a photograph of the dusted ice surface and Figure 7b is the same photograph converted to a binary image. The areal coverage was then estimated using a computer program that determines the area covered by black (the leaves and stems) in relation to the total area*. In this example, 30% of the area was covered by leaves and stems.

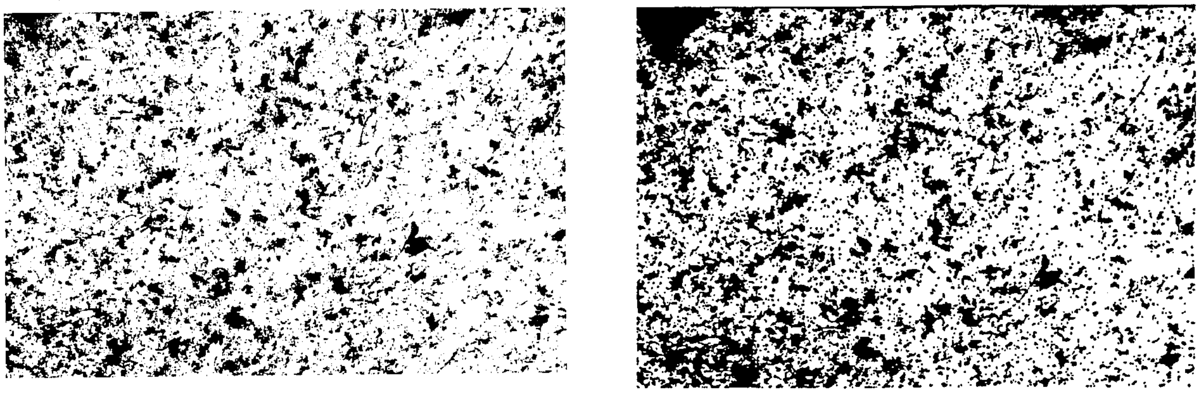
The leaves used for this study were mulched by the Town of Montpelier. The objective in mulching the leaves was to reduce the leaves to mulched particles that were approximately the size of a postage stamp. Mulched to this size, about four bags of leaves yield one bag of leaf mulch.

The hydroseeder used for this operation was a Bowie model 2500 hydroseeder. We found that 18 to 20 fifty-gallon bags of leaf mulch added to the 2,500 gal. (9,500 L) of water produced a slurry that could be easily sprayed. By volume that is roughly 2.7 m^3 of leaf mulch. By weight it was an estimated 540 kg of leaf mulch.

Montpelier, Vermont

The Winooski River has repeatedly had ice jams

*The value for the aerial coverage depends on how the analyst classifies the gray areas when creating the binary image from the black-and-white photograph.



a. Photograph.

b. Binary image of the dusted surface (black portions are interpreted as leaves).

Figure 7. Dusted surface in Montpelier, Vermont.

which caused flooding in Montpelier, Vermont, the most recent of which occurred on 11 March 1992. Figure 8 shows a map of the area of concern in Montpelier. From the historical record we find that jams frequently formed at or near Cemetery Bend (indicated in Fig. 8). The annual formation of a stable ice cover, that extends from the I-89 bridge to the Bailey Avenue bridge, causes the broken ice from upstream to arrest and jam at this location (U.S. Army Corps of Engineers 1994b). It was hypothesized that thinning or weakening the ice through this reach may allow the broken ice to be carried out of the city rather than jamming there. We selected two locations along this problem area for testing the hydroseeder and leaf mulch on the Winooski River. The locations are indicated by the cross-hatched sections in Figure 8. The area labeled A was located between the railroad trestle and Bailey Avenue Bridge. Businesses are located on both sides of the river at this site; thus it provided a good test of the ability of the hydroseeder to work in tight confines. The area labeled B extended upstream from the I-89 bridge to Cemetery Bend. This site had easy access from Route 2, which allowed us to evaluate deployment of the mulch using the hydroseeder's cannon. Both of these sites were dusted on 9 March 1994.

Bailey Avenue (Site A)

For the test section at the Bailey Avenue Bridge (site A), wood markers were placed on the ice to indicate the location to be dusted and the amount of thinning of the ice that occurred in the test section. Holes were drilled in the ice and one end of the wood cross was put into the hole with the cross-piece laying on the ice (see Fig. 9). As the ice thinned, the bottom of the cross-piece indicated the elevation of the top of the original ice surface. If snow fell on the leaves the markers indicated where the leaves were located under the snow.

The leaf mulch was put on the ice by using a 200-ft (60-m) length of fire hose with a 3/4-in. (1.9-mm) nozzle (the hydroseeder is capable of operating with up to 400 feet [120 m] of hose). The area covered using the hose is indicated in Figure 10 and was approximately 4,000 m^2. It took about 1 hour to do this. The remainder of the 9,500 L slurry was spread using the hydroseeder's cannon aimed upstream from the Bailey Avenue Bridge, and

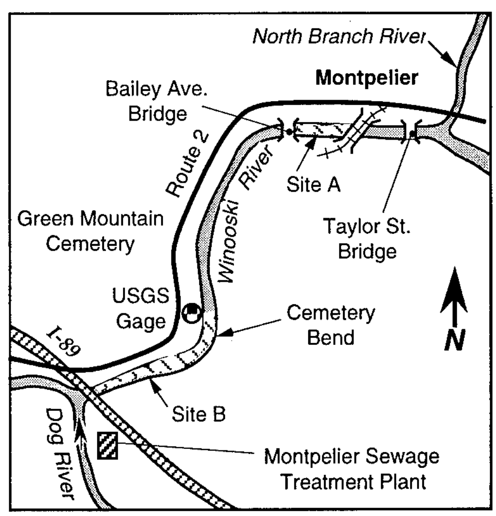


Figure 8. Location of the test sites on the Winooski River in Montpelier, Vermont.

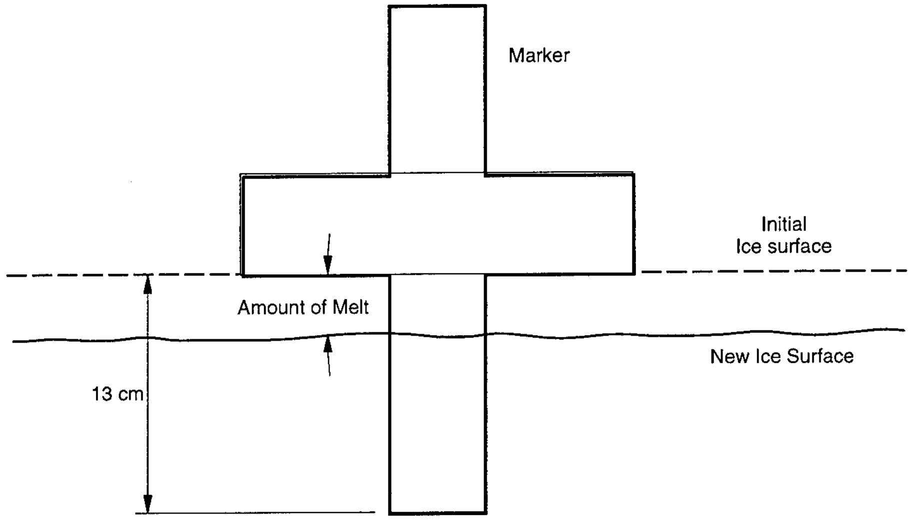


Figure 9. Schematic of stakes used to locate leaves and document ice depletion.

across the river at the railroad bridge (Fig. 11 shows the cannon in use). At both of these locations the hydroseeder was about 4.5 m above the ice surface. The spray from the hydroseeder projected out about 40 m across the ice. The area covered using the cannon was approximately 3,200 m^2. It took roughly 10 minutes to cover this area. Thus the total area covered using both the hose and cannon was almost 8000 m^2 (the total river area in this reach was 13,200 m^2). The areal coverage was about 30%; there was approximately 70 g of material per square meter.

The dusting pattern shown in Figure 10 was chosen in an attempt to weaken the ice cover using a minimum amount of mulch. Rather than melt all of the ice, the rationale was to melt break lines into the ice for it to fail along. Then these smaller pieces would easily wash out with the spring runoff. The chevrons (Fig. 10) were oriented to try to channel surface runoff from the adjacent parking lots out to the middle of the ice cover, thereby accelerating the ice decay.

Interstate 89 (Site B)

We spread 9,500 L of slurry at this site from Route 2 using the hydroseeder's cannon. We covered 0.5 km of the river between I-89 and cemetery bend in about 20 minutes. The total area of coverage was again about 8,000 m^2. The density of coverage was about the same as at the Bailey Avenue Bridge.

History of the ice decay

The initial thickness of the ice at site A and B

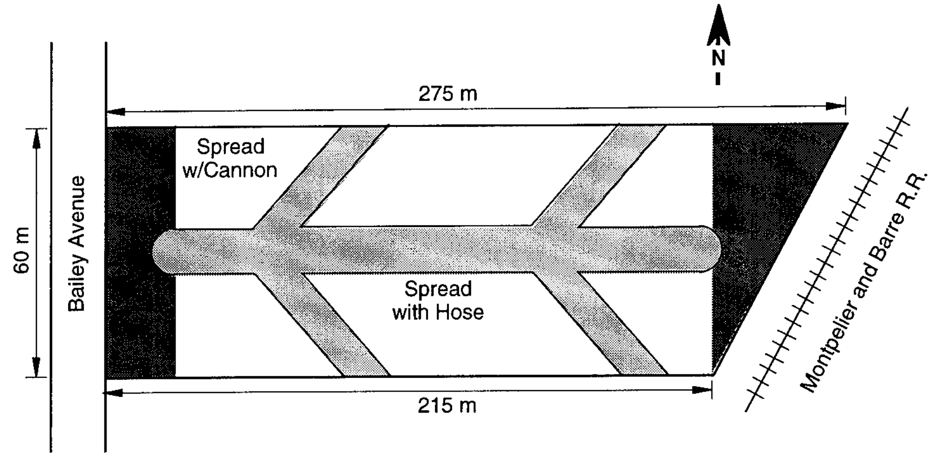


Figure 10. Detail of dusting at site A in Montpelier, Vermont.

Figure 11. Hydroseeder being used to put leaves on the White River in Hartford, Vermont (March 1994).

was about 50 cm, and was covered by 5 to 15 cm of snow. The leaves were applied on top of the snow. The estimated solar radiation and air temperature for Montpelier* and snow depth at the site A during the test period is plotted in Figure 12.

The day after the leaves were put on the ice 6.5 cm of snow fell, burying the leaves. By 18 March the leaves at site A were covered by about 15 to 20 cm of snow. Nevertheless, on the 23rd the overlying snow had completely melted in the dusted area at both sites, while the undusted area was covered by an estimated 10–15 cm of snow. When the ice washed out of both test sections on the 27th, there was still snow on the undusted ice, but the dusted ice was free of snow.

Although no snow measurements were taken at site B, observations indicated that the melting in this area was probably similar to that at site A. This section of the river was less shaded than site A so we expect the melting may have been accelerated in this reach compared to site A.

*The met data were obtained from the Barre–Montpelier Airport, which is located about 4 miles from the test sites.

White River Junction, Vermont

The White River, from the confluence with the Connecticut to the Hartford Village Bridge (Fig. 13), has a history of ice jams with no fewer than nine major jams forming in this reach since the turn of the century. The most recent jam occurred in the spring of 1990 and resulted in the collapse of two piers and loss of a span on the Bridge Street crossing. The two sites we chose to dust (sites C and D in Fig. 13) are historical ice jam locations. The dusting was accomplished on 17 March 1994. We placed six stakes in the ice at each test section so we could measure the amount of thinning in this region. The configuration of the stakes is shown in Figure 14.

Bridge Street Bridge (Site C)

Due to a dwindling supply of mulched leaves, only eleven bags of mulched leaves were added to the 9,500 L of water and used at the Bridge Street Bridge. Stakes were placed on the ice at regular intervals perpendicular to the north bank of the river, so we could measure the distance the hydroseeder could spray the leaves using the cannon. We found using the 1-in. (2.5-mm) nozzle the hydroseeder had a range of 40 m. The flared nozzle cut down the range to 30 m. From the bridge,

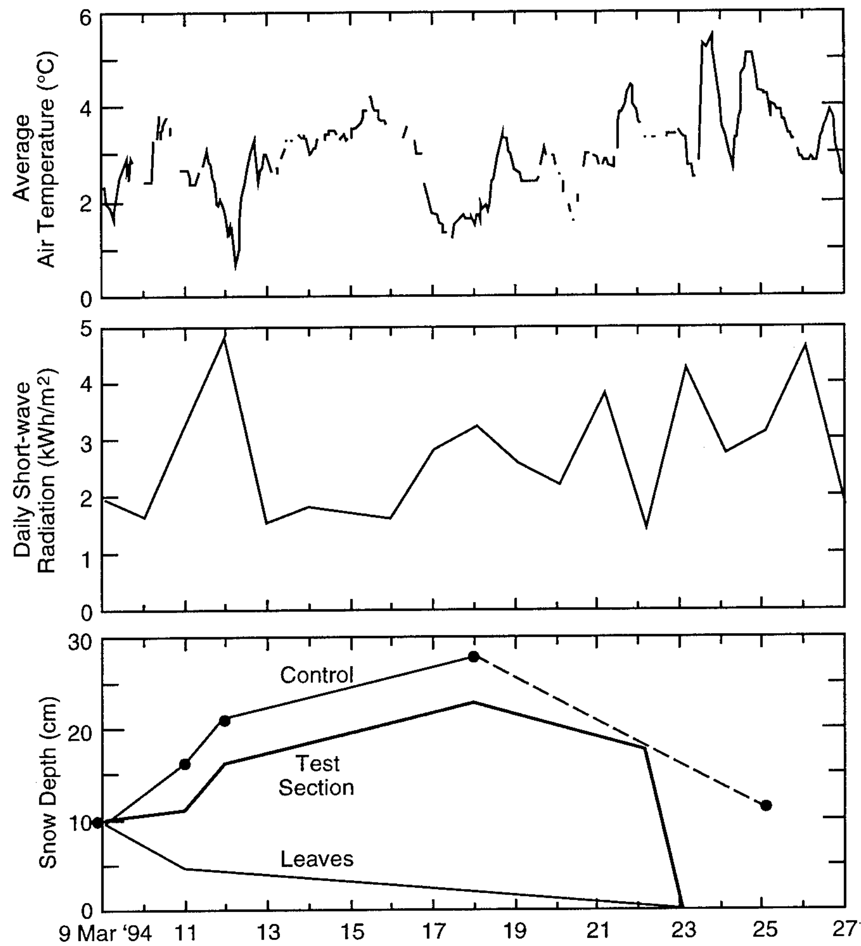


Figure 12. Meteorological conditions and snow cover depth during the field tests on the Winooski River in Montpelier, Vermont.

shooting with the wind, the range increased to about 43 m.

Only half of the 9,500 L slurry was used at this site. The areal coverage was around 50–80%, or about 190 g/m^2 by weight. The total area of coverage was about 2,800 m^2.

Hartford Village Bridge (Site D)

At this site 11 bags of leaves were added to the 4,800 L of slurry left over from the Bridge Street Bridge. The hydroseeder was also refilled to its 9,500-L capacity, so for this site we had a mixture of approximately 18 bags of leaves in the 9,500-L slurry.

This bridge is about 15 m above the ice; thus we were able to get far better range with the 1-in. nozzle previously used. As a result we used the 1-in. nozzle to spread the leaves farther away from the bridge and the flared nozzle to deliver the leaves closer to the bridge. The areal coverage here was in the 80% range, or about 190 g/m^2 by weight. The area of coverage was about 2,800 m^2.

History of the ice decay

The air temperature and estimated incident solar radiation during the test period are shown in Figure 15. These data come from the Lebanon Regional Airport, which was about 2 miles from the test sites. Also Figure 15 gives a plot of the ice thickness for site C and snow cover for both sites during the tests.

From Figure 15 we can see that leaves were effective in melting the snow and ice in the test sections. The average ice thickness in the test reach is about 3–5 cm thinner in the test reach than in the control after 13 days. This represents a lost in ice thickness of about 0.3–0.4 cm/day. We note that the 6 cm of snow that was deposited on the ice on the 22nd was melted off the test section the following day. However, in the control section the

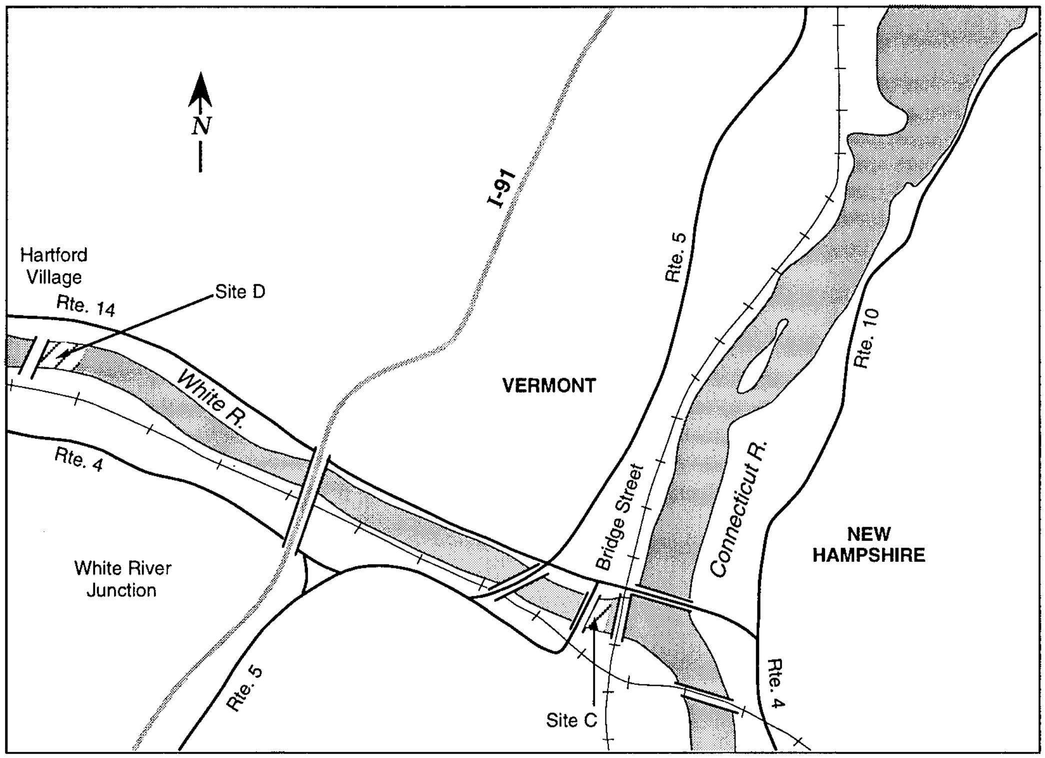


Figure 13. Location of the test sites on the White River in Hartford, Vermont.

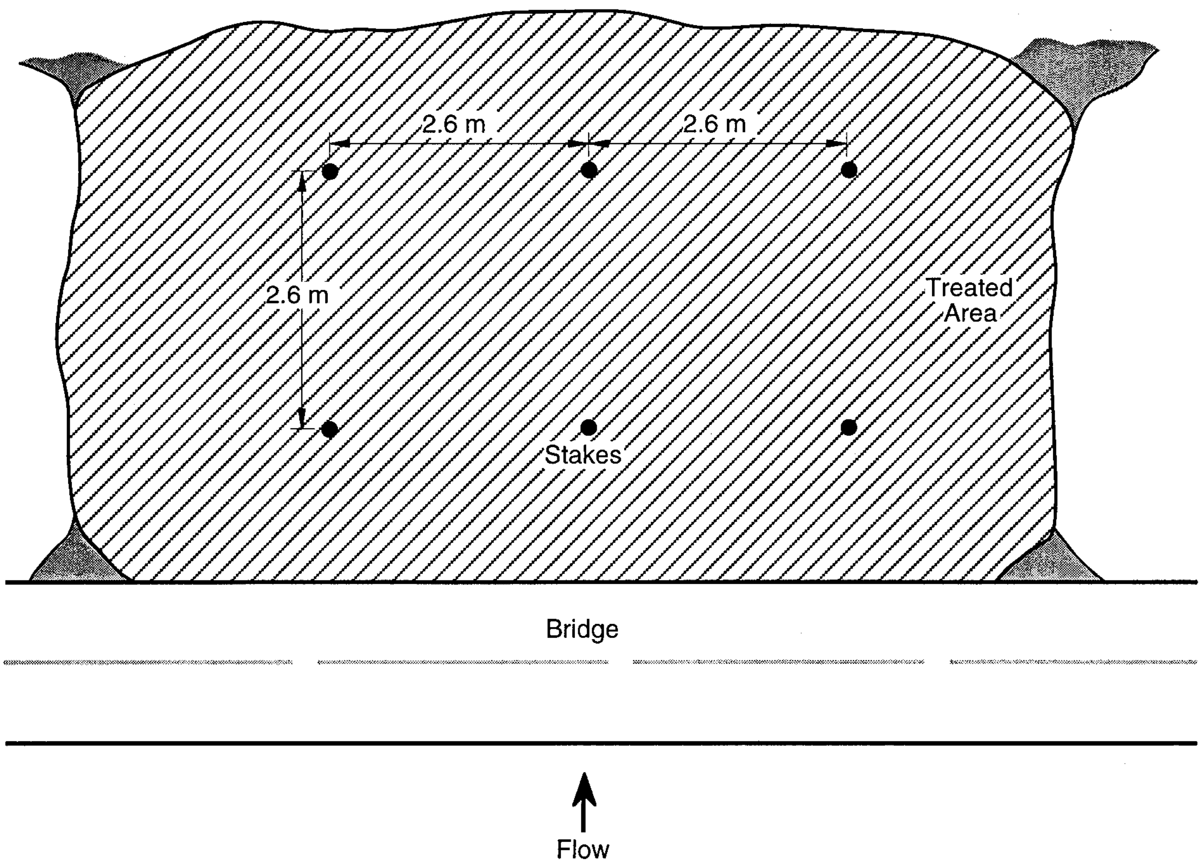


Figure 14. Layout of stakes on the ice for both the Bridge St. and Hartford Village Bridge test sites.

snow lingered on the ice for another week before melting off. This insulating snow can be very effective at shielding the ice from solar radiation as well as protecting the ice from warmer air temperatures. Both of these factors combine to delay ice melt and deterioration.

Cost estimates

The costs for dusting using the hydroseeder are enumerated below. The base costs listed below are the costs per day of the equipment and labor used in this project. Since we were not charged for the labor or front loader (both were supplied by the City of Montpelier) we provide estimates of those base costs. There was no cost for the leaves since these were annually collected and disposed of by the City of Montpelier. Thus, the only additional costs to the city for the leaves was mulching them.

Base Costs	
Hydroseeder	$1600/day
Mulching leaves	
Leaf mulcher	50/day
Labor (2 laborers @ $25.00 / hour each)	400/day
Loader and operator	$300/day

Since it took about an hour to fill the hydroseeder with leaves and water and to dust 8,000 m^2 using the cannon, we estimated that using the hydroseeder for a full day (8 hours) we could dust 64,000 m^2. A front-end loader was used to load the leaves into the hydroseeder and we have included one day's service for a loader and operator. From our experience we required 18 bags of mulch to cover 8,000 m^2. It takes 8 hours for two workers to mulch 20 bags of leaves; thus to mulch

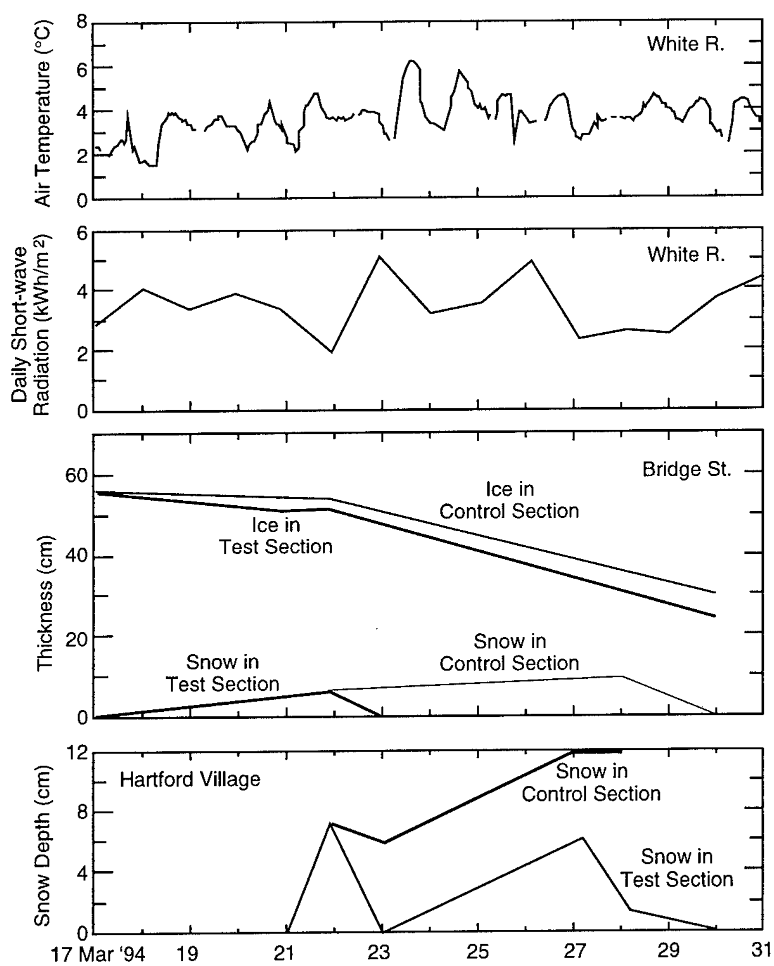


Figure 15. Meteorological conditions, snow cover depth, and ice thickness during the field tests on the White River in Hartford, Vermont.

enough leaves to cover 64,000 m^2 (144 bags) would take 7.2 days. The rent for the leaf mulcher would then be for 8 days, since we could not rent the mulcher for a fraction of a day.

Based on the above discussion the cost per covered hectare (10,000 m^2) is listed below.

Estimated costs for covering one hectare using the hydroseeder cannon

Hydroseeder	$247
Leaf mulcher	62
Labor	450
Loader and operator	47
Total	$806/hectare

If we were to recalculate that based on the rate of application using the hose instead of the cannon, we would need to effectively double the amount per hectare for the hydroseeder and loader. This would total about $1,100/ha.

We compare these costs to the costs incurred for the dusting operations in Galena, Alaska, and on the Platte River in Nebraska. The best estimate of costs for the dusting in Alaska come from the records of the Alaska Division of Emergency Services, which has coordinated the dusting operation for the last nine years. Here we present the costs for the most recent dusting operation at Galena which was done in 1993. In this application 92 m^2 of sand were used. The application rate was about 0.27 kg/m^2 and that sand weighs about 1300 kg/m^3 (U.S. Army Corps of Engineers 1968). The total cost for the operation was $33,000. The cost estimate per covered hectare is about $754 (in 1993 dollars).

In the spring of 1994 the Omaha District initiated a dusting operation on the Platte River. Here it used 27,200 kg of coal slag. This operation cost $20,000 to dust 8 ha with coal slag (U.S. Army Corps of Engineers 1994). This cost included $4,500 for use of a National Guard helicopter to document the operation and the ice decay. The cost per hectare for this operation was $2,470. If we remove the cost for the helicopter, the cost for the operation drops to $1,938/ha. Even at this, the cost is more than double the cost of the operation at Galena, Alaska. We attribute the lower cost for the operation at Galena to the 25 years of experience in dusting and the attendant cost optimization that can occur with such experience.

Environmental considerations

As previously mentioned coal dust and slag are considered a threat to the riverine aquatic life due to the contaminants they contain. Before using the leaves in a field trial we had the leaves chemically analyzed using X-ray fluorescence (Hewitt 1994) to check for the presence of heavy metals, as these could be harmful to the stream habitat if present in high concentrations. For comparison we present the chemical composition of the coal slag used on the Platte River in Table 1.

The results of the X-ray fluorescence analysis of the leaf mulch shows that the leaves did not contain any heavy metals. The only metal constituent found in the leaves was iron, with a concentration of 0.05 percent by weight. We note that the coal slag (Table 1) has an iron concentration over 100 times greater than the leaves. The coal slag also contains other metals that the leaves do not, namely aluminum, magnesium, titanium and sodium, all of which occur at high levels. From these chemical analyses we conclude that the leaf mulch is more environmentally acceptable than the use of coal slag. However, to avoid unnecessary introduction of contaminants to the riverine environment, we recommend that leaves collected for such a dusting operation should be taken from a "clean" area to avoid the inclusion of insecticides, lubricants, etc., in the leaves.

Aside from the introduction of contaminants, small particles such as sand, coal dust and slag can be a problem in many New England rivers, since they can clog the spaces between rocks where the fish like to lay their eggs and thereby inhibit reproduction. Since leaves are biodegradable and are naturally deposited in rivers, they are readily absorbed into the river with only a fraction of their total weight going to silting. Thus, in principle, using leaves should not adversely impact the fish

Table 1. Chemical analysis of coal slag (or bottom slag) (U.S. Army Corps of Engineers 1979).

Ingredient	*Amount (%)*
Silicon	23.3
Aluminum	11.3
Calcium	5.4
Iron	5.2
Sulfur	3.1
Magnesium	1.4
Potassium	0.93
Titanium	0.64
Undetermined	0.54
Sodium	0.20
Phosphorus	0.11

habitat, provided the amount of leaves added to the river by dusting does not exceed the aerobic capacity of the river (i.e., the decaying leaves use all of the dissolved oxygen in the river).

Minshall et al. (1983) indicate that the leaf concentration that falls into Northeastern rivers of the size like the Winooski and White is around 100 to 200 g/m^2. The estimated leaf coverages from these dusting tests on the Winooski and White Rivers were 60 and 190 g/m^2, respectively. Thus, the amount of leaves spread on the ice in both Montpelier and Hartford is about the same as what falls naturally on the river in the fall, effectively doubling the annual amount of leaves going into the treated reach. This increased leaf loading is expected to affect the acidity and turbidity of the water as well as affect the level of dissolved solids and fine particles in the water. To what degree this impacts the riverine habitat requires further study.

Discussion of field test results

From the tests both at Montpelier and White River we demonstrated the effectiveness of spreading leaves on the ice using a hydroseeder. We found that considerable amount of area can be covered in a short time using this method. Taking into consideration time for refilling the seeder's tank and travel time from the filling station to the river, 6.4 hectares could be covered per day using this method. At this rate of application we estimate the cost per dusted hectare to be about $806. This compares favorably with dusting using aircraft, which we estimate could cost $754/ha. Accessibility to the river is necessary for using a hydroseeder. A location where a road runs parallel to the river is ideal for using a hydroseeder. Even with the 120-m hose that is available for the hydroseeder, there needs to be good access to the river if the hydroseeder is to be used for dusting. Rates of coverage using the hydroseeder are cut in half if the hose is used instead of the cannon. Consequently we could expect the cost per hectare using the hose to be around $1,100.

The leaves proved to be effective for melting snow even when covered by up to 33 cm of snow. It may be effective for snow depths greater than this, but that was the deepest snow we observed during our test period. From Dozier et al. (1989) we find that incident solar radiation can penetrate snow depths of 10 to 20 cm, but the fraction of transmitted radiation decreases exponentially with snow depth. Thus, we expect that snow depths much greater than 18 cm may block any radiation from reaching the leaves. Even though the ice may not deteriorate while the leaves are covered by snow, the presence of the leaves melts the overlying snow sooner. Thus, the ice surface will be exposed to solar radiation, thereby hastening ice decay.

The conditions under which this evaluation was performed were less than ideal. There were only seven days of cloudless weather during the 21-day evaluation at Montpelier and five cloudless days during the 13 days at Hartford. Nevertheless, at Montpelier we observed the snow deteriorated faster in the test section over the 16-day period from 9 March to 25 March. We saw similar results at the test sites in Hartford. Additionally, at the one Hartford site we saw a noticeable decrease in the ice cover thickness in the test section of about 0.3–0.4 cm per day as compared to the control. Since this is a modest amount of ice loss we hesitate to say that the leaves were effective in melting the ice cover, since variability in the river hydraulics throughout the test reach could confound these results. Nevertheless, the trend shows promise, and requires further work to confirm the effectiveness of leaves for melting an ice cover.

We cannot say that we promoted premature release of the ice due to our efforts. Nonetheless, it is clear that the leaf mulch was effective in reducing the thickness of ice in the Bridge Street test area, which would result in weaker ice in that area than otherwise would have existing naturally.

CONCLUSIONS AND RECOMMENDATIONS

From the tests conducted on the ice-covered pond, we found that dusting can reduce the albedo of the snow and ice from 0.5–0.9 to 0.1–0.2. This reduction in surface albedo was shown to accelerate the melting of the snow cover and the thinning of the ice cover on the pond. Of the materials tested we found sand, coal dust and leaves were the most effective at reducing the albedo of snow and ice surfaces. We found that the leaves and sand were about equal in their ability to accelerate the melting of snow and ice. The leaves naturally occur in New England rivers and are biodegradable; thus, used in moderate amounts, they should not adversely affect the stream habitat.

From the field trial conducted on two Vermont rivers we found the leaves were effective at melting the snow cover, even when covered with up to 13 cm of snow. It is less clear how effective the leaves were at melting the ice cover, although the

results show a trend toward reduced ice cover thickness in the test section as compared to the control. The use of a hydroseeder for spreading the dusting material is effective and is comparable in cost to aerial dusting. However, there must be good access to the river bank to use the hydroseeder to spread the leaves. The ideal situation would be where a road runs along the side of a river.

More work is required to find the extent to which dusting can reduce the ice volume and strength. This will require measurements of the ice thickness and strength in the dusted and undusted reaches during the spring melt period leading up to breakup. Concurrent measurements of solar radiation, ice temperature, water temperature, air temperature and other standard meteorological data will also be required to document the decay process and all the pertinent heat and mass transfer processes occurring at the ice surface. Also a greater understanding of when and where to dust to achieve maximum benefit needs to be established. To do this, a relationship linking ice volume and ice strength to ice jam potential needs to be developed. Finally, further work is required to determine the environmental impact of dusting with leaves on the riverine habitat.

LITERATURE CITED

Ashton, G.D. (1985) Deterioration of floating ice covers. *Journal of Energy Resources,* **107:** 177–182.

Ashton, G.D., Ed. (1986) *River and Lake Ice Engineering.* Littleton, Colorado: Water Resources Publications.

Colbeck, S.C. (1988) Snowmelt increase through albedo reduction. USA Cold Regions Research and Engineering Laboratory, Special Report 88-26.

Dozier, J., R.E. Davis and A.W. Nolin (1989) Reflectance and transmittance of snow at high spectral resolution. *Proceedings of International Geoscience and Remote Sensing Symposium '89,* p. 662–664.

Hewitt, A.D. (1994) Screening for metals by X-ray fluorescence spectrometry/response factor/Compton K_α peak normalization analysis. *American Environmental Laboratory,* June.

Hoffer, R.M. (1978) Biological and physical characterizations in applying computer aided techniques to remote sensor data. In *Remote Sensing: The Quantitative Approach* (P.H. Swain and S.M. Davis, Ed.), p. 227–290.

Labsphere, Inc. (1988) Spectralon product data sheet. North Sutton, New Hampshire.

Minshall, G.W., R.C. Peterson, K.W. Cummings, T.L. Bott, J.R. Sedeil, C.E. Cushing and R.L. Vannote (1983) Interbiome comparison of stream ecosystem dynamics. *Ecological Monographs,* **53:** 1–25.

Perovich, D.K. (1992) Light reflection from sea ice cover during the onset of summer melt. *Ocean Optics XI,* p. 3351–3358.

Prowse, T.D and M.N Demuth (1992) Spatial and temporal variability of river ice-cover strength. *9th International Northern Research Basins Symposium/Workshop,* p. 405–421.

Slaughter, C.W. (1969) Snow albedo modification: A review of literature. USA Cold Regions Research and Engineering Laboratory, Technical Report 217.

Swain, P.H. and S.M. Davis, Ed. (1978) *Remote Sensing: The Quantitative Approach.* New York: McGraw Hill.

U.S. Army Corps of Engineers (1968) Operation Dusty Alaska. U.S. Army Engineer District, Alaska.

U.S. Army Corps of Engineers (1979) Ice dusting of the Platte River. U.S. Army Engineer District, Omaha, March.

U.S. Army Corps Of Engineers (1994a) Ice dusting of the Platte River. U.S. Army Engineer District, Omaha, September.

U.S. Army Corps of Engineers (1994b) Winooski River flood control reconnaissance study, City of Montpelier, Vermont. Prepared for U.S. Army Engineer District, New York.

Williams, G.P. (1967) Ice dusting experiments to increase the rate of melting ice. National Research Council, Ottawa, Canada, Technical paper No. 239.

APPENDIX A: ESTIMATING THE INCIDENT SOLAR RADIATION USING CLOUD COVER DATA

Since the solar radiation was not measured at the test sites in Montpelier and White River, we estimated the incident solar radiation on our test plots. The procedure for this is described in Ashton (1985, 1986). We outline that procedure here and add to it our procedure for incorporating hourly cloud cover information in the calculation.

The solar radiation incident to the earth's atmosphere is called the solar constant, I_o, and is taken to be 1380 W/m^2. The proportion of I_o that strikes the earth's surface on a clear day $\phi_{so,c}$ is a function of latitude, L, declination angle, δ, and time of day:

$$\phi_{so,c} = \frac{I_o \sin^2 \alpha}{(\sin\alpha + 2.7)e_a 10^{-3} + 1.085 \sin\alpha + 0.10} \quad \text{(A1)}$$

where e_a is the vapor pressure of water in the atmosphere, and

$$\sin\alpha = \sin L \sin\delta + \cos L \cos\delta \cos H. \quad \text{(A2)}$$

In eq A2, H is the hour angle of the sun that is computed from

$$H \ (hour - 12)15°. \quad \text{(A3)}$$

The declination angle is determined from

$$\delta = 23.45° \cos\left(\frac{360}{365}[172 - D]\right) \quad \text{(A4)}$$

where D is the Julian day. The vapor pressure e_a is

$$e_a = e_{sat} RH \quad \text{(A5)}$$

where e_{sat} is the water vapor saturation pressure at the given air temperature, T_a, and RH is the relative humidity. The saturation pressure can be found from

$$e_{sat} = 6.11e^{\frac{17.3T_a}{T_a + 237.3}}. \quad \text{(A6)}$$

The incident solar radiation with a cloud cover, ϕ_s, is

$$\phi_s = \phi_{so,c}(1 - 0.6C) \quad \text{(A7)}$$

were C is the percent cloud cover. The constant 0.6 is empirically determined and may be adjusted to make this expression better fit local conditions. However, for our sites we found that 0.6 gave good agreement with measured solar radiation.

The cloud cover, as reported by the Barre–Montpelier Airport and Lebanon Regional Airport, is reported as falling into one of seven categories shown in Table A1. For each category we assigned a value for C as shown in Table A1. The exception to this is for missing data; in that case the cloud cover was interpolated from the data before and after the missing point(s).

The daily solar radiation values were then determined by summing the hourly estimates from eq A7 and Table A1. These results are plotted in Figures 12 and 15.

This procedure was checked by comparing actual solar radiation measurements made at the CRREL meteorological test cell in Hanover, with the solar radiation

Table A1. Cloud cover categories.

Category	*Cloud cover, C*
Clear	0
Scattered	0.33
Broken	0.67
Overcast	1
Obscured	1
Partially obscured	1
Missing	—

estimates based on the cloud cover reported at the Lebanon Regional Airport, in West Lebanon, New Hampshire. These two locations are separated by a distance of about 6 miles. The results of the comparison are shown in Figure A1. In Figure A1 we plot the total daily solar radiation and the accumulated solar radiation. The accumulated solar radiation is a summation of the daily radiation to date. The accumulated solar radiation is set to zero on the day the leaves were put on the ice.

The discrepancy between the two sites is generally less 25%. The largest discrepancies occur on thickly overcast days where the estimates overpredict the incoming radiation by a factor of 2 to 5. However, looking at the accumulated solar radiation, we found that on average the errors in the estimate seem to cancel each other out over the long term. As a result we see that both the measured and estimated values agree very well.

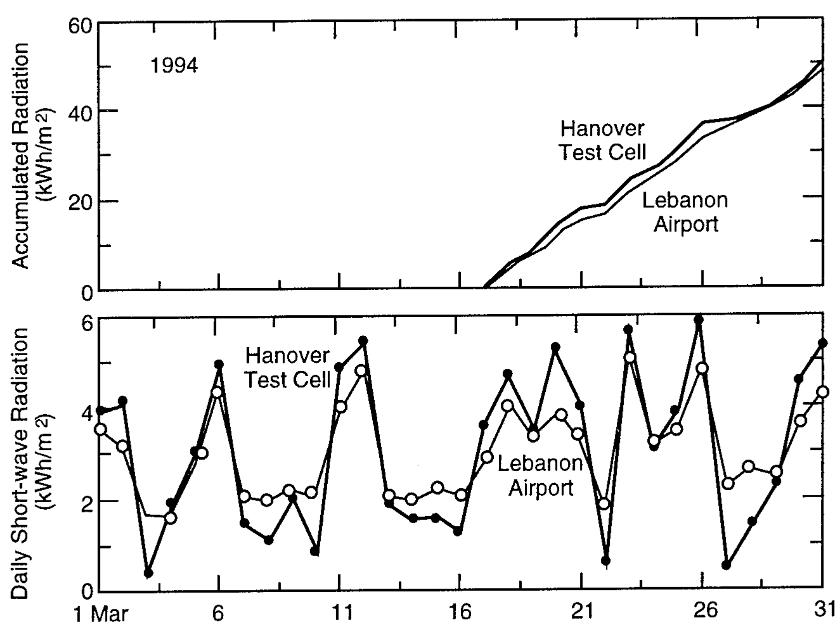


Figure A1. Comparison of solar radiation measurements taken at the Hanover test cell located at CRREL and the estimated solar radiation based on cloud cover data at Lebanon Regional Airport, Lebanon, New Hampshire.

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13. ABSTRACT (*Maximum 200 words*)

In an effort to find a low cost means of reducing ice jams on small rivers in New England, dusting with organic matter was field tested during the spring of 1993 and 1994. Test squares on a pond located at CRREL in Hanover, New Hampshire, were dusted with several materials to evaluate their effectiveness in accelerating snow melting and ice deterioration. Leaf mulch was included in the materials tested because, unlike other materials used in the past to weaken ice (e.g., fly ash or coal slag), leaves are naturally found in rivers and should not adversely affect aquatic organisms when applied in small quantities. It was found from these tests that the leaves perform about the same as the traditionally used dusting materials. To transfer what was learned at the pond tests to a field application, two rivers in Vermont, with a known history of ice jams, were dusted using leaf mulch during the spring of 1994. Since these sites were located on narrow rivers that wind through highly populated areas, aerial dusting was not possible. For these sites we used a hydroseeder to spread the leaves on the ice. Application of leaf mulch with a hydroseeder was found to be an efficient method of putting the leaves on the ice. After the rivers were dusted we had a heavy snowfall, and were not able to determine the effectiveness of the leaf mulch in melting the ice. Observations suggest, however, that the leaf mulch helped melt the overlying snow. More work is needed to determine the effectiveness of leaf mulch to weaken ice and how much ice weakening is necessary to reduce the severity of ice jams.

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